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# Doses for Various Pathways to Man Based on Unit Concentrations of Radionuclides Pertinent to Decontamination and Decommissioning of Properties

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# DOSES FOR VARIOUS PATHWAYS TO MAN BASED ON UNIT CONCENTRATIONS OF RADIONUCLIDES PERTINENT TO DECONTAMINATION AND DECOMMISSIONING OF PROPERTIES

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# DOSES FOR VARIOUS PATHWAYS TO MAN BASED ON UNIT CONCENTRATIONS OF RADIONUCLIDES PERTINENT TO DECONTAMINATION AND DECOMMISSIONING OF PROPERTIES

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## ABSTRACT

This report gives dose tabulations for unit concentrations of radionuclides likely to be encountered in the decommissioning of real estate contaminated with uranium and thorium ores and residues. The reported doses may be ratioed to known air, soil, and water concentrations, exposure times, and intakes to estimate the total radiation dose for individuals exposed to the facilities. These dose estimates may be used in developing criteria to determine appropriate remedial actions for returning the properties to useful purposes and for establishing restrictions for such use.

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## I. INTRODUCTION

During the period of development of the nuclear program, many nuclear research and uranium processing facilities have been placed in protective storage or abandoned status. There is a need to make sure that these facilities are decontaminated to levels such that they no longer present a potential radiological hazard to the general public and that they can, if possible, be returned to some useful purpose.

In the decontamination and decommissioning of these various contaminated properties, the dose to man from all significant pathways and for differing mixtures of radionuclides will have to be considered in the development of criteria for public usage of the facilities. To aid radiation dose estimation, tables of doses for all significant pathways to man have been developed. The doses have been calculated for continuous exposure at the location where the unit concentration of radionuclides exists. It is proposed that the doses in these tables may be ratioed to fit site-specific, measured concentrations of radionuclides, dietary intake, time spent in the area of question, and other known exposure parameters.

All internal doses listed in the tables are 50-year dose commitments; that is, the total dose an individual will receive from one year of intake integrated over the next 50 years of his life. For those materials that either have short radioactive half-lives or are eliminated rapidly from the body, essentially all the dose is received in the same year that the radionuclide entered the body, and the annual dose rate is about the same as the 50-year dose commitment. All external doses are given as annual dose rates.

The factors for converting internal exposure to dose (dose conversion factors) were determined using ICRP-2 (Ref. 1) and other recognized values and implemented by recent models for the lung[2] and GI tract.[3] Details of these models and the assumptions used in calculating the dose conversion factors are described by Dunning *et al.*[4] The dose conversion factors used for external radiation dose determinations are given in ORNL-4992. (Ref. 5) The methodology and assumptions used in the dose calculations are discussed in Section IV, Appendix to this report.

## II. HOW TO USE THE TABLES FOR SITE-SPECIFIC DOSE DETERMINATION

In almost all cases of dose calculations, maximum conditions of exposure were assumed. For example, the individual, unless otherwise stipulated, spends all of his time outdoors with no shielding. All of his foods are grown or produced on the contaminated land, and all of his fish and drinking water come directly from the contaminated stream (no reduction of water contamination by filtration was considered). As a result of these and other assumptions, the doses listed may be increased or reduced directly by the ratio of the actual concentration of the radionuclide; they may be reduced further by the fraction of time that the individual spends away from home as well as the amount of food and water he gets outside of the contaminated area.

In estimating the dose from exposure to external gamma radiation resulting from contaminated ground surfaces, the exposed individual is represented by a point receptor 1 m above the ground. The ground is modeled as a plane surface with a uniform distribution of activity. No environmental movement in the soil beyond the depth of 1.5 cm and no shielding or removal processes are included. Thus, the dose estimates are conservative (tend to overestimate the potential dose) and are based on the assumption of uniform deposition of the radionuclide particulates over a given area for the total airborne emissions during the lifetime of the facility.

Example I. In Table 11 the dose to the bone from drinking water from a stream contaminated by $^{238}U$ (in equilibrium with its short-lived daughters) to a level of 1 pCi/ml is 310 millirem per year. If the site-specific measurement of an actual stream shows a level of 1 x $10^{-2}$ pCi/ml, the dose would be 0.01 x 310 or 3.1 millirem per year.

Additionally, if the individual obtains only two-thirds of his water supply from the contaminated stream during the year, the dose would be only two-thirds of 3.1 millirem per year or 2.1 millirem per year.

The dose for each radionuclide in the stream is adjusted to the actual concentration and intake parameters and then summed to give the total estimated dose from this pathway.

Example II. In Tables 3 and 4 the external doses to an individual from contaminated ground surfaces are given. These doses are for the individual spending all of his time outdoors (Table 3) or all of his time indoors (Table 4). The total-body dose from $^{214}Bi$ in Table 3 is 4.2 millirem per year; in Table 4 it is 0.76 millirem per year. If the individual spends 50% of his time outside the house and 50% inside the house, his dose would be one-half of 4.2 plus one-half of 0.76 or 2.48 millirem per year.

Example III. In Table 2 the dose to the bone from the inhalation of resuspended particles of $^{238}U$ is $9.8 \times 10^{-2}$ millirem per year based on a resuspension factor of $1 \times 10^{-9}$ $m^{-1}$ for normal activity. Should a farmer live on the soil and spend a portion of the year disturbing the soil mechanically (for example, plowing), the resuspension factor would be $1 \times 10^{-7}$ (see Appendix). Thus, the dose would be a factor of 100 greater than the dose for normal activity or 9.8 millirem per year. If he spends only one month plowing and the rest of his time (11 months) in normal activity, his total dose from the resuspended $^{238}U$ radionuclide would be $(1/12 \times 9.8) + (11/12 \times 9.8 \times 10^{-2})$ or $9.1 \times 10^{-1}$ millirem per year.

## III. INDEX OF DOSE TABLES FOR VARIOUS PATHWAYS

Table 1. Dose commitments[a] from inhalation of contaminated air.[b] Figures are based on a unit concentration in the air of 1 $pCi/m^3$ for each radionuclide (lung clearance rate class W; particle size of 1 μm)

| Radionuclide | Dose (millirem per year) | | | |
|---|---|---|---|---|
| | Total body | Bone | Kidneys | Lungs |
| Uranium series | | | | |
| $^{238}U$ | 4.1 E1[c] | 4.4 E2 | 1.9 E1 | 2.1 E2 |
| $^{234}Th$ | 3.9 E-2 | 9.3 E-2 | 3.7 E-2 | 1.5 |
| $^{234m}Pa$ | 3.8 E-6 | 2.0 E-7 | 9.0 E-8 | 2.6 E-4 |
| $^{234}U$ | 4.6 E1 | 5.0 E2 | 2.1 E1 | 2.4 E2 |
| $^{230}Th$ | 1.5 E3 | 1.7 E4 | 9.9 E2 | 2.4 E2 |
| $^{226}Ra$ | 3.9 E1 | 9.2 E1 | 2.9 E2 | 2.4 E2 |
| $^{222}Rn$ | 1.5 E-4 | 5.0 E-5 | 6.1 E-5 | 1.0 E-2 |
| $^{218}Po$ | 1.9 E-3 | 3.3 E-3 | 5.6 E-3 | 1.1 E-1 |
| $^{214}Pb$ | 8.6 E-3 | 1.2 E-3 | 3.7 E-2 | 5.0 E-1 |
| $^{214}Bi$ | 6.4 E-3 | 3.3 E-3 | 3.7 E-2 | 4.0 E-1 |
| $^{214}Po$ | 8.6 E-10 | 2.1 E-10 | 7.6 E-12 | 6.0 E-8 |
| $^{210}Pb$ | 6.6 E1 | 8.8 E2 | 1.4 E1 | 2.7 E1 |
| $^{210}Bi$ | 1.2 E-1 | 1.9 E-1 | 3.6 | 4.5 |
| $^{210}Po$ | 6.6 | 1.7 E1 | 6.1 E1 | 1.9 E2 |
| Actinium series | | | | |
| $^{235}U$ | 4.2 E1 | 4.5 E2 | 1.9 E1 | 2.1 E2 |
| $^{231}Th$ | 1.2 E-3 | 4.9 E-3 | 4.7 E-4 | 3.3 E-2 |
| $^{231}Pa$ | 3.8 E3 | 4.7 E4 | 1.9 E3 | 2.4 E2 |

Table 1. (continued)

| Radionuclide | Dose (millirem per year) | | | |
|---|---|---|---|---|
| | Total body | Bone | Kidneys | Lungs |
| Actinium series | | | | |
| $^{227}Ac$ | 2.4 E3 | 3.1 E4 | 1.1 E3 | 3.6 E2 |
| $^{227}Th$ | 9.2 | 7.3 E1 | 3.0 E1 | 2.3 E2 |
| $^{223}Ra$ | 4.8 | 3.9 E1 | 1.1 | 2.0 E2 |
| $^{219}Rn$ | 5.7 E-5 | 1.1 E-5 | 6.0 E-6 | 3.9 E-3 |
| $^{211}Pb$ | 9.5 E-3 | 1.1 E-2 | 9.2 E-3 | 6.0 E-1 |
| $^{211}Bi$ | 5.8 E-4 | 4.2 E-5 | 7.4 E-4 | 4.0 E-2 |
| $^{207}Tl$ | 9.2 E-6 | 4.3 E-7 | 2.2 E-6 | 6.2 E-4 |
| Thorium series | | | | |
| $^{232}Th$ | 1.5 E3 | 1.8 E4 | 8.6 E2 | 2.0 E2 |
| $^{228}Ra$ | 4.1 E1 | 1.1 E2 | 6.8 | 2.2 E1 |
| $^{228}Ac$ | 1.2 E-1 | 1.3 | 6.0 E-1 | 2.0 E-1 |
| $^{228}Th$ | 2.7 E2 | 3.2 E3 | 1.3 E2 | 5.0 E2 |
| $^{224}Ra$ | 1.1 | 1.0 | 3.6 E-1 | 3.8 E1 |
| $^{220}Rn$ | 1.4 E-4 | 6.2 E-5 | 3.5 E-5 | 9.3 E-3 |
| $^{212}Pb$ | 1.6 E-1 | 5.6 E-1 | 5.7 E-1 | 7.7 |
| $^{212}Bi$ | 1.9 E-2 | 6.7 E-3 | 1.6 E-1 | 1.2 |
| $^{208}Tl$ | 1.9 E-5 | 8.6 E-6 | 9.4 E-6 | 6.0 E-4 |

Table 1. (continued)

| Radionuclide | Dose (millirem per year) | | | |
|---|---|---|---|---|
| | Total body | Bone | Kidneys | Lungs |
| Plutonium | | | | |
| $^{238}Pu$ | 1.5 E3 | 1.7 E4 | 9.8 E2 | 2.7 E2 |
| $^{239}Pu$ | 1.6 E3 | 1.9 E4 | 1.1 E3 | 2.5 E2 |

[a]Fifty-year dose commitment for one year of intake.

[b]Assumed continuous exposure and an inhalation rate of 23 $m^3$ of air per day.

[c]Read as $4.1 \times 10^1$.

Table 1(a). Dose commitments[a] from inhalation of contaminated air.[b] Figures are based on a unit concentration in the air of 1 pCi/m$^3$ for each radionuclide (clearance rate class Y; 1 μm particle size)

| Radionuclide | Dose (millirem per year) | | | |
|---|---|---|---|---|
| | Total body | Bone | Kidneys | Lungs |
| Uranium series | | | | |
| $^{238}$U | 7.4 E1[c] | 1.5 E2 | 6.6 | 2.1 E3 |
| $^{234}$Th | 3.3 E-2 | 5.8 E-3 | 2.4 E-3 | 2.0 |
| $^{234m}$Pa | 3.8 E-6 | 2.5 E-8 | 2.0 E-8 | 2.6 E-4 |
| $^{234}$U | 8.2 E1 | 1.7 E2 | 7.3 | 2.3 E3 |
| $^{230}$Th | 6.6 E2 | 7.0 E3 | 4.0 E2 | 2.2 E3 |
| $^{226}$Ra | 3.9 E1 | 9.2 E1 | 2.9 | 2.4 E2 |
| $^{222}$Rn | 1.5 E-4 | 5.0 E-5 | 6.1 E-5 | 1.0 E-2 |
| $^{218}$Po | 1.9 E-3 | 3.3 E-3 | 5.6 E-3 | 1.1 E-1 |
| $^{214}$Pb | 8.6 E-3 | 1.2 E-3 | 3.7 E-2 | 5.0 E-1 |
| $^{214}$Bi | 6.4 E-3 | 3.3 E-3 | 3.7 E-2 | 4.8 E-1 |
| $^{214}$Po | 8.6 E-10 | 2.1 E-10 | 7.6 E-12 | 6.0 E-8 |
| $^{210}$Pb | 6.6 E1 | 8.8 E2 | 1.4 E1 | 2.7 E1 |
| $^{210}$Bi | 1.2 E-1 | 1.9 E-1 | 3.6 | 4.5 |
| $^{210}$Po | 6.6 | 1.7 E1 | 6.1 E1 | 1.9 E2 |
| Actinium series | | | | |
| $^{235}$U | 7.5 E1 | 1.5 E2 | 6.7 | 2.1 E3 |
| $^{231}$Th | 8.9 E-4 | 1.6 E-3 | 1.0 E-4 | 3.5 E-2 |
| $^{231}$Pa | 1.7 E3 | 2.0 E4 | 8.3 E2 | 2.5 E3 |
| $^{227}$Ac | 1.1 E3 | 1.1 E4 | 4.0 E2 | 4.4 E3 |
| $^{227}$Th | 5.0 | 8.2 | 3.8 E-1 | 2.9 E2 |

Table 1(a). (continued)

| Radionuclide | Dose (millirem per year) | | | |
|---|---|---|---|---|
| | Total body | Bone | Kidneys | Lungs |
| Actinium series | | | | |
| $^{223}Ra$ | 4.8 | 3.9 | 1.1 | 2.0 E2 |
| $^{219}Rn$ | 5.7 E-5 | 1.1 E-5 | 6.0 E-6 | 3.9 E-3 |
| $^{211}Pb$ | 9.5 E-3 | 1.1 E-2 | 9.2 E-3 | 6.0 E-1 |
| $^{211}Bi$ | 5.8 E-4 | 4.2 E-5 | 7.4 E-4 | 4.0 E-2 |
| $^{207}Tl$ | 9.2 E-6 | 4.3 E-7 | 2.2 E-6 | 6.2 E-4 |
| Thorium series | | | | |
| $^{232}Th$ | 6.6 E2 | 7.3 E3 | 3.5 E2 | 1.9 E3 |
| $^{228}Ra$ | 4.1 E-1 | 1.1 E2 | 6.8 | 2.2 E1 |
| $^{228}Ac$ | 4.2 E-1 | 2.2 E-1 | 1.0 E-2 | 1.1 |
| $^{228}Th$ | 1.2 E2 | 5.8 E2 | 2.7 E1 | 3.1 E3 |
| $^{224}Ra$ | 1.1 | 1.0 | 3.6 E-1 | 3.8 E1 |
| $^{220}Rn$ | 1.4 E-4 | 6.2 E-5 | 3.5 E-5 | 9.3 E-3 |
| $^{212}Pb$ | 1.6 E-1 | 5.6 E-1 | 5.7 E-1 | 7.7 |
| $^{212}Bi$ | 1.9 E-2 | 6.7 E-3 | 1.6 E-1 | 1.2 |
| $^{208}Tl$ | 1.9 E-5 | 8.6 E-6 | 9.4 E-6 | 6.0 E-4 |
| Plutonium | | | | |
| $^{238}Pu$ | 6.4 E2 | 6.6 E3 | 3.9 E2 | 2.6 E3 |
| $^{239}Pu$ | 7.2 E2 | 7.7 E3 | 4.4 E2 | 2.5 E3 |

[a]Fifty-year dose commitment for one year of intake.

[b]Assumed continuous exposure and an inhalation rate of 23 $m^3$ of air per day.

[c]Read as $7.4 \times 10^1$.

Table 2. Dose commitments[a] resulting from inhalation[b] of resuspended[c] radionuclides from contaminated soil. Figures are based on a unit concentration of 1 pCi/g of each radionuclide in the soil. (Clearance rate class W; particle size of 1 μm)

| Radionuclide | Dose (millirem per year) | | | |
|---|---|---|---|---|
| | Total body | Bone | Kidneys | Lungs |
| Uranium series | | | | |
| $^{238}U$ | 9.3 E-3[d] | 9.8 E-2 | 4.3 E-3 | 4.7 E-2 |
| $^{234}Th$ | 8.9 E-6 | 2.1 E-5 | 8.2 E-6 | 3.4 E-4 |
| $^{234m}Pa$ | 8.6 E-10 | 4.5 E-11 | 2.0 E-11 | 5.9 E-8 |
| $^{234}U$ | 1.0 E-2 | 1.1 E-1 | 4.7 E-3 | 5.3 E-2 |
| $^{230}Th$ | 3.3 E-1 | 3.9 | 2.2 E-1 | 5.3 E-2 |
| $^{226}Ra$ | 8.7 E-3 | 2.1 E-2 | 6.4 E-4 | 5.3 E-2 |
| $^{218}Po$ | 4.2 E-7 | 7.4 E-7 | 1.3 E-6 | 2.4 E-5 |
| $^{214}Pb$ | 1.9 E-6 | 2.7 E-7 | 8.4 E-6 | 1.1 E-4 |
| $^{214}Bi$ | 1.4 E-6 | 7.3 E-7 | 8.3 E-6 | 9.1 E-5 |
| $^{214}Po$ | 1.9 E-13 | 4.6 E-14 | 1.7 E-15 | 1.3 E-11 |
| $^{210}Pb$ | 1.5 E-2 | 2.0 E-1 | 3.2 E-3 | 6.0 E-3 |
| $^{210}Bi$ | 2.7 E-5 | 4.2 E-5 | 8.1 E-4 | 1.0 E-3 |
| $^{210}Po$ | 1.5 E-3 | 3.8 E-3 | 1.4 E-2 | 4.3 E-2 |
| Actinium series | | | | |
| $^{235}U$ | 9.4 E-3 | 1.0 E-1 | 4.3 E-3 | 4.7 E-2 |
| $^{231}Th$ | 2.6 E-7 | 1.1 E-6 | 1.1 E-7 | 7.4 E-6 |
| $^{231}Pa$ | 8.5 E-1 | 1.0 E1 | 4.3 E-1 | 5.5 E-2 |
| $^{227}Ac$ | 5.5 E-1 | 6.9 | 2.4 E-1 | 8.1 E-2 |
| $^{227}Th$ | 2.1 E-3 | 1.6 E-2 | 6.8 E-4 | 5.1 E-2 |

Table 2. (continued)

| Radionuclide | Dose (millirem per year) | | | |
|---|---|---|---|---|
| | Total body | Bone | Kidneys | Lungs |
| Actinium series | | | | |
| $^{223}Ra$ | 1.1 E-3 | 8.9 E-4 | 2.5 E-4 | 4.5 E-2 |
| $^{211}Pb$ | 2.1 E-6 | 2.4 E-6 | 2.1 E-6 | 1.4 E-4 |
| $^{211}Bi$ | 1.3 E-7 | 9.4 E-9 | 1.7 E-7 | 8.9 E-6 |
| $^{207}Tl$ | 2.1 E-9 | 9.7 E-11 | 4.9 E-10 | 1.4 E-7 |
| Thorium series | | | | |
| $^{232}Th$ | 3.3 E-1 | 4.0 | 1.9 E-1 | 4.5 E-2 |
| $^{228}Ra$ | 9.3 E-3 | 2.5 E-2 | 1.5 E-3 | 4.9 E-3 |
| $^{228}Ac$ | 2.6 E-5 | 3.0 E-4 | 1.3 E-5 | 4.5 E-5 |
| $^{228}Th$ | 6.0 E-2 | 7.2 E-1 | 3.0 E-2 | 1.1 E-1 |
| $^{224}Ra$ | 2.5 E-4 | 2.3 E-4 | 8.0 E-5 | 8.5 E-3 |
| $^{212}Pb$ | 3.6 E-5 | 1.2 E-4 | 1.3 E-4 | 1.7 E-3 |
| $^{212}Bi$ | 4.2 E-6 | 1.5 E-6 | 3.6 E-5 | 2.6 E-4 |
| $^{208}Tl$ | 4.3 E-9 | 1.9 E-9 | 2.1 E-9 | 1.4 E-7 |
| Plutonium | | | | |
| $^{238}Pu$ | 3.3 E-1 | 3.8 | 2.2 E-1 | 6.0 E-2 |
| $^{239}Pu$ | 3.6 E-1 | 4.3 | 2.5 E-1 | 5.7 E-2 |

[a]Fifty-year dose commitment for one year of intake.
[b]Assumed inhalation of 23 $m^3$ of air per day.
[c]Assumed resuspension factor of $1 \times 10^{-9}$ $m^{-1}$.
[d]Read as $9.3 \times 10^{-3}$.

Table 2(a). Dose commitments[a] resulting from inhalation[b] of resuspended[c] radionuclides from contaminated soil. Figures based on a unit concentration of 1 pCi/g of each radionuclide in the soil (clearance rate class Y; 1 μm particle size)

| Radionuclide | Dose (millirem per year) | | | |
|---|---|---|---|---|
| | Total body | Bone | Kidneys | Lungs |
| Uranium series | | | | |
| $^{238}U^{d}$ | 1.7 E-2[e] | 3.4 E-2 | 1.5 E-3 | 4.7 E-1 |
| $^{234}Th^{d}$ | 7.4 E-6 | 1.3 E-6 | 5.3 E-7 | 4.5 E-4 |
| $^{234m}Pa^{d}$ | 8.6 E-10 | 5.6 E-12 | 4.5 E-12 | 5.9 E-8 |
| $^{234}U^{d}$ | 1.9 E-2 | 3.8 E-2 | 1.6 E-3 | 5.2 E-1 |
| $^{230}Th^{d}$ | 1.5 E-1 | 1.6 | 9.1 E-2 | 5.0 E-1 |
| $^{226}Ra$ | 8.7 E-3 | 2.1 E-2 | 6.4 E-4 | 5.3 E-2 |
| $^{218}Po$ | 4.2 E-7 | 7.4 E-7 | 1.3 E-6 | 2.4 E-5 |
| $^{214}Pb$ | 1.9 E-6 | 2.7 E-7 | 8.4 E-6 | 1.1 E-4 |
| $^{214}Bi$ | 1.4 E-6 | 7.3 E-7 | 8.3 E-6 | 9.1 E-5 |
| $^{214}Po$ | 1.9 E-13 | 4.6 E-14 | 1.7 E-15 | 1.3 E-11 |
| $^{210}Pb$ | 1.5 E-2 | 2.0 E-1 | 3.2 E-3 | 6.0 E-3 |
| $^{210}Bi$ | 2.7 E-5 | 4.2 E-5 | 8.1 E-4 | 1.0 E-3 |
| $^{210}Po$ | 1.5 E-3 | 3.8 E-3 | 1.4 E-2 | 4.3 E-2 |
| Actinium series | | | | |
| $^{235}U^{d}$ | 1.7 E-2 | 3.4 E-2 | 1.5 E-3 | 4.7 E-1 |
| $^{231}Th^{d}$ | 2.0 E-7 | 3.6 E-7 | 2.3 E-8 | 7.8 E-6 |
| $^{231}Pa^{d}$ | 3.9 E-1 | 4.6 | 1.9 E-1 | 5.7 E-1 |
| $^{227}Ac^{d}$ | 2.4 E-1 | 2.5 | 9.1 E-2 | 9.9 E-1 |
| $^{227}Th^{d}$ | 1.1 E-3 | 1.9 E-3 | 8.5 E-5 | 6.6 E-2 |

Table 2(a). (continued)

| Radionuclide | Dose (millirem per year) | | | |
|---|---|---|---|---|
| | Total body | Bone | Kidneys | Lungs |
| Actinium series | | | | |
| $^{223}Ra$ | 1.1 E-3 | 8.9 E-4 | 2.5 E-4 | 4.5 E-2 |
| $^{211}Pb$ | 2.1 E-6 | 2.4 E-6 | 2.1 E-6 | 1.4 E-4 |
| $^{211}Bi$ | 1.3 E-7 | 9.4 E-9 | 1.7 E-7 | 8.9 E-6 |
| $^{207}Tl$ | 2.1 E-9 | 9.7 E-11 | 4.9 E-10 | 1.4 E-7 |
| Thorium series | | | | |
| $^{232}Th^{d}$ | 1.5 E-1 | 1.6 | 7.9 E-2 | 4.4 E-1 |
| $^{228}Ra$ | 9.3 E-3 | 2.5 E-2 | 1.5 E-3 | 4.9 E-3 |
| $^{228}Ac^{d}$ | 9.4 E-6 | 4.9 E-5 | 2.4 E-6 | 2.5 E-4 |
| $^{228}Th^{d}$ | 2.6 E-2 | 1.3 E-1 | 6.0 E-3 | 6.9 E-1 |
| $^{224}Ra$ | 2.5 E-4 | 2.3 E-4 | 8.0 E-5 | 8.5 E-3 |
| $^{212}Pb$ | 3.6 E-5 | 1.2 E-4 | 1.3 E-4 | 1.7 E-3 |
| $^{212}Bi$ | 4.2 E-6 | 1.5 E-6 | 3.6 E-5 | 2.6 E-4 |
| $^{208}Tl$ | 4.3 E-9 | 1.9 E-9 | 2.1 E-9 | 1.4 E-7 |
| Plutonium | | | | |
| $^{238}Pu^{d}$ | 1.4 E-1 | 1.5 | 8.7 E-2 | 5.8 E-1 |
| $^{239}Pu^{d}$ | 1.6 E-1 | 1.7 | 9.8 E-2 | 5.6 E-1 |

[a]Fifty-year dose commitment for one year of intake.

[b]Assumed inhalation of 23 $m^3$ of air per day.

[c]Assumed resuspension factor of $1 \times 10^{-9}$ $m^{-1}$.

[d]Clearance rate class Y; all other radionuclides are in class W.

[e]Read as $1.7 \times 10^{-2}$.

Table 3. Annual dose from exposure to external gamma radiation resulting from contaminated ground surfaces.[a] Figures are based on a unit concentration of 1 pCi/g for each radionuclide[b]

| Radionuclide | Dose (millirem per year) | | | |
|---|---|---|---|---|
| | Total body | Bone | Kidneys | Lungs |
| Uranium series | | | | |
| $^{238}U$ | 7.1 E-3[c] | 6.9 E-3 | 1.6 E-3 | 2.2 E-3 |
| $^{234}Th$ | 3.7 E-2 | 6.7 E-2 | 2.7 E-2 | 3.1 E-2 |
| $^{234m}Pa$ | 2.8 E-2 | 3.2 E-2 | 2.6 E-2 | 2.6 E-2 |
| $^{234}U$ | 1.1 E-2 | 1.3 E-2 | 3.5 E-3 | 4.4 E-3 |
| $^{230}Th$ | 1.4 E-2 | 2.0 E-2 | 6.6 E-3 | 8.1 E-3 |
| $^{226}Ra$ | 2.1 E-2 | 3.3 E-2 | 1.5 E-2 | 1.9 E-2 |
| $^{222}Rn$ | 1.1 E-3 | 1.4 E-3 | 1.0 E-3 | 1.0 E-3 |
| $^{218}Po$ | 2.5 E-4 | 2.7 E-4 | 2.3 E-4 | 2.3 E-4 |
| $^{214}Pb$ | 7.1 E-1 | 9.7 E-1 | 5.8 E-1 | 6.5 E-1 |
| $^{214}Bi$ | 4.2 | 4.6 | 3.3 | 4.0 |
| $^{214}Po$ | 3.0 E-4 | 3.3 E-4 | 2.8 E-4 | 2.8 E-4 |
| $^{210}Pb$ | 5.1 E-2 | 3.8 E-2 | 2.7 E-2 | 3.2 E-2 |
| $^{210}Bi$ | 0.0 | 0.0 | 0.0 | 0.0 |
| $^{210}Po$ | 0.0 | 0.0 | 0.0 | 0.0 |
| Actinium series | | | | |
| $^{235}U$ | 6.5 E-1 | 1.0 | 4.6 E-1 | 5.7 E-1 |
| $^{231}Th$ | 2.8 E-1 | 4.8 E-1 | 1.8 E-1 | 2.1 E-1 |
| $^{231}Pa$ | 4.1 E-1 | 4.1 E-1 | 4.1 E-1 | 4.1 E-1 |
| $^{227}Ac$ | 3.0 E-6 | 1.8 E-4 | 3.0 E-6 | 3.9 E-5 |

Table 3. (continued)

| Radionuclide | Dose (millirem per year) | | | |
|---|---|---|---|---|
| | Total body | Bone | Kidneys | Lungs |
| $^{227}Th$ | 6.1 E-1 | 6.1 E-1 | 6.1 E-1 | 6.1 E-1 |
| $^{223}Ra$ | 5.7 E-1 | 5.7 E-1 | 5.7 E-1 | 5.7 E-1 |
| $^{219}Rn$ | 1.6 E-1 | 2.2 E-1 | 1.3 E-1 | 1.5 E-1 |
| $^{211}Pb$ | 1.4 E-1 | 1.7 E-1 | 1.3 E-1 | 1.3 E-1 |
| $^{211}Bi$ | 1.4 E-1 | 1.7 E-1 | 1.2 E-1 | 1.3 E-1 |
| $^{207}Tl$ | 7.4 E-3 | 7.4 E-3 | 7.4 E-3 | 7.4 E-3 |
| Thorium series | | | | |
| $^{232}Th$ | 8.0 E-3 | 9.5 E-3 | 2.2 E-3 | 3.1 E-3 |
| $^{228}Ra$ | 1.5 E-1 | 2.3 E-1 | 8.4 E-2 | 7.6 E-2 |
| $^{228}Ac$ | 2.0 | 2.3 | 1.7 | 1.9 |
| $^{228}Th$ | 3.7 E-2 | 6.1 E-2 | 2.5 E-2 | 1.3 E-2 |
| $^{220}Rn$ | 1.0 E-3 | 1.3 E-3 | 9.2 E-4 | 9.8 E-4 |
| $^{224}Ra$ | 2.9 E-2 | 4.5 E-2 | 2.1 E-2 | 2.6 E-2 |
| $^{212}Pb$ | 4.5 E-1 | 7.1 E-1 | 3.2 E-1 | 3.9 E-1 |
| $^{212}Bi$ | 3.4 E-1 | 3.9 E-1 | 2.8 E-1 | 3.2 E-1 |
| $^{208}Tl$ | 8.2 | 8.8 | 6.6 | 7.8 |
| Plutonium | | | | |
| $^{238}Pu$ | 7.3 E-3 | 5.6 E-3 | 7.8 E-4 | 1.3 E-3 |
| $^{239}Pu$ | 3.1 E-3 | 2.7 E-3 | 5.2 E-4 | 7.3 E-4 |

[a]Assumed exposure without structural shielding 100% of the time. No shielding by rough terrain considered.

[b]Soil contaminated to a depth of 1.5 cm. Soil density of 1.5 g/cm$^3$. The ground is modeled as a plane surface with uniform distribution of activity. No environmental downward movement beyond the depth of 1.5 cm is included.

[c]Read as $7.1 \times 10^{-3}$.

Table 4. Annual dose to an individual inside a structure[a] from exposure[b] to external gamma radiation resulting from outside, contaminated ground surfaces. Figures are based on a unit concentration of 1 pCi/g of each radionuclide in the soil[c]

| Radionuclide | Dose (millirem per year) | | | |
|---|---|---|---|---|
| | Total body | Bone | Kidneys | Lungs |
| Uranium series | | | | |
| $^{238}U$ | 1.3 E-11[d] | 1.3 E-11 | 3.0 E-12 | 4.1 E-12 |
| $^{234}Th$ | 1.3 E-5 | 2.4 E-5 | 9.8 E-6 | 1.1 E-5 |
| $^{234m}Pa$ | 3.6 E-3 | 8.6 E-3 | 3.4 E-3 | 3.4 E-3 |
| $^{234}U$ | 1.0 E-7 | 1.2 E-7 | 3.3 E-8 | 4.1 E-8 |
| $^{230}Th$ | 9.1 E-7 | 1.3 E-6 | 4.3 E-7 | 5.3 E-7 |
| $^{226}Ra$ | 3.3 E-4 | 5.1 E-4 | 2.3 E-4 | 2.9 E-4 |
| $^{222}Rn$ | 1.1 E-4 | 1.4 E-4 | 1.0 E-4 | 1.0 E-4 |
| $^{218}Po$ | 0.0 | 0.0 | 0.0 | 0.0 |
| $^{214}Pb$ | 3.5 E-2 | 4.8 E-2 | 2.9 E-2 | 3.2 E-2 |
| $^{214}Bi$ | 7.6 E-1 | 8.4 E-1 | 6.0 E-1 | 7.3 E-1 |
| $^{214}Po$ | 4.3 E-5 | 4.7 E-5 | 4.0 E-5 | 4.0 E-5 |
| $^{210}Pb$ | 5.5 E-10 | 9.5 E-5 | 2.9 E-10 | 3.5 E-10 |
| $^{210}Bi$ | 0.0 | 0.0 | 0.0 | 0.0 |
| $^{210}Po$ | 0.0 | 0.0 | 0.0 | 0.0 |
| Actinium series | | | | |
| $^{235}U$ | 8.2 E-3 | 1.3 E-2 | 5.8 E-3 | 7.2 E-3 |
| $^{231}Th$ | 2.7 E-5 | 4.7 E-5 | 1.7 E-5 | 2.0 E-5 |
| $^{231}Pa$ | 2.4 E-3 | 2.4 E-3 | 2.4 E-3 | 2.4 E-3 |
| $^{227}Ac$ | 1.4 E-9 | 8.3 E-8 | 1.4 E-9 | 1.8 E-8 |

Table 4. (continued)

| Radionuclide | Dose (millirem per year) | | | |
|---|---|---|---|---|
| | Total body | Bone | Kidneys | Lungs |
| Actinium series | | | | |
| $^{227}Th$ | 8.5 E-3 | 8.5 E-3 | 8.5 E-3 | 8.5 E-3 |
| $^{223}Ra$ | 1.0 E-2 | 1.0 E-2 | 1.0 E-2 | 1.0 E-2 |
| $^{219}Rn$ | 9.3 E-3 | 1.3 E-2 | 7.5 E-3 | 8.7 E-3 |
| $^{211}Pb$ | 1.6 E-2 | 2.0 E-2 | 1.5 E-2 | 1.5 E-2 |
| $^{211}Bi$ | 8.3 E-3 | 1.0 E-2 | 7.1 E-3 | 7.7 E-3 |
| $^{207}Tl$ | 1.1 E-3 | 1.1 E-3 | 1.1 E-3 | 1.1 E-3 |
| Thorium series | | | | |
| $^{232}Th$ | 1.0 E-7 | 1.2 E-7 | 2.9 E-8 | 4.1 E-8 |
| $^{228}Ra$ | 0.0 | 0.0 | 0.0 | 0.0 |
| $^{228}Ac$ | 2.5 E-1 | 2.8 E-1 | 2.1 E-1 | 2.3 E-1 |
| $^{228}Th$ | 2.1 E-5 | 3.4 E-5 | 1.4 E-5 | 7.3 E-6 |
| $^{220}Rn$ | 1.1 E-4 | 1.4 E-4 | 9.8 E-5 | 1.0 E-4 |
| $^{224}Ra$ | 1.0 E-3 | 1.6 E-3 | 7.4 E-4 | 9.1 E-4 |
| $^{212}Pb$ | 1.0 E-2 | 1.6 E-2 | 7.3 E-3 | 8.9 E-3 |
| $^{212}Bi$ | 4.3 E-2 | 4.9 E-2 | 3.5 E-2 | 4.0 E-2 |
| $^{208}Tl$ | 1.9 | 2.0 | 1.5 | 1.8 |
| Plutonium | | | | |
| $^{238}Pu$ | 1.0 E-10 | 7.7 E-11 | 1.1 E-11 | 1.8 E-11 |
| $^{239}Pu$ | 6.4 E-8 | 5.6 E-8 | 1.1 E-8 | 1.5 E-8 |

[a] Dose reduction factor based on person standing in the middle of a 30 × 30 ft. solid concrete block (blocks 8 in. thick) house.

[b] Continuous exposure (100% of time spent inside house).

[c] Soil contaminated to a depth of 1.5 cm. Soil density of 1.5 g/cm$^3$.

[d] Read as $1.3 \times 10^{-11}$.

Table 5. Dose commitments[a] from direct consumption of contaminated soil (pica). Figures are based on a unit concentration of 1 pCi/g of each radionuclide in the soil and an intake of 1 g of soil per day

| Radionuclide | Dose (millirem per year) | | | |
|---|---|---|---|---|
| | Total body | Bone | Kidneys | Lungs |
| Uranium series | | | | |
| $^{238}U$ | 2.3 E-2[b] | 2.6 E-1 | 1.1 E-1 | 1.2 E-5 |
| $^{234}Th$ | 2.4 E-4 | 5.0 E-5 | 2.3 E-5 | 6.6 E-7 |
| $^{234m}Pa$ | 8.3 E-8 | 6.4 E-10 | 3.1 E-9 | 1.5 E-9 |
| $^{234}U$ | 2.5 E-2 | 2.9 E-1 | 1.2 E-2 | 1.2 E-5 |
| $^{230}Th$ | 5.1 E-1 | 6.2 | 3.5 E-1 | 1.3 E-6 |
| $^{226}Ra$ | 1.4 | 3.6 | 1.1 E-1 | 2.4 E-4 |
| $^{218}Po$ | 3.2 E-6 | 1.9 E-5 | 2.4 E-5 | 3.0 E-7 |
| $^{214}Pb$ | 2.0 E-5 | 8.5 E-5 | 1.6 E-4 | 2.8 E-6 |
| $^{214}Bi$ | 9.7 E-6 | 3.6 E-5 | 7.7 E-5 | 2.3 E-6 |
| $^{214}Po$ | 4.9 E-13 | 4.4 E-12 | 1.3 E-13 | 3.8 E-17 |
| $^{210}Pb$ | 1.4 | 1.9 E1 | 1.8 E-1 | 2.8 E-5 |
| $^{210}Bi$ | 6.1 E-4 | 1.2 E-3 | 6.9 E-2 | 1.9 E-11 |
| $^{210}Po$ | 1.1 E-1 | 4.7 E-1 | 1.8 | 4.1 E-9 |
| Actinium series | | | | |
| $^{235}U$ | 2.3 E-2 | 2.6 E-1 | 1.1 E-2 | 2.3 E-5 |
| $^{231}Th$ | 2.9 E-5 | 4.2 E-6 | 2.3 E-6 | 2.3 E-7 |
| $^{231}Pa$ | 1.4 | 1.7 E1 | 6.9 E-1 | 1.6 E-4 |
| $^{227}Ac$ | 8.8 E-1 | 1.1 E1 | 4.0 E-1 | 1.3 E-4 |
| $^{227}Th$ | 4.5 E-3 | 5.1 E-2 | 2.2 E-3 | 3.8 E-6 |
| $^{223}Ra$ | 1.0 E-1 | 2.1 E-1 | 5.1 E-2 | 1.9 E-5 |
| $^{211}Pb$ | 1.3 E-5 | 6.3 E-5 | 2.4 E-5 | 2.5 E-7 |

Table 5. (continued)

| Radionuclide | Dose (millirem per year) | | | |
|---|---|---|---|---|
| | Total body | Bone | Kidneys | Lungs |
| $^{211}Bi$ | 2.4 E-7 | 3.4 E-8 | 2.6 E-7 | 1.1 E-8 |
| $^{207}Tl$ | 2.3 E-7 | 3.7 E-8 | 1.9 E-8 | 1.1 E-9 |
| Thorium series | | | | |
| $^{232}Th$ | 5.1 E-1 | 6.6 | 3.1 E-1 | 3.8 E-4 |
| $^{228}Ra$ | 1.4 | 3.6 | 1.4 E-1 | 8.1 E-4 |
| $^{228}Ac$ | 9.5 E-6 | 4.5 E-4 | 6.9 E-5 | 9.5 E-6 |
| $^{228}Th$ | 9.9 E-2 | 1.2 | 5.1 E-2 | 2.3 E-5 |
| $^{224}Ra$ | 3.0 E-2 | 5.8 E-2 | 1.9 E-2 | 3.2 E-5 |
| $^{212}Pb$ | 1.5 E-3 | 1.7 E-2 | 6.5 E-3 | 1.9 E-5 |
| $^{212}Bi$ | 3.3 E-5 | 4.6 E-5 | 1.0 E-5 | 4.7 E-6 |
| $^{208}Tl$ | 1.2 E-6 | 3.7 E-8 | 1.8 E-6 | 9.4 E-7 |
| Plutonium | | | | |
| $^{238}Pu$ | 1.6 E-2 | 1.8 E-1 | 1.1 E-2 | 2.9 E-8 |
| $^{239}Pu$ | 1.8 E-2 | 2.1 E-1 | 1.2 E-2 | 2.2 E-8 |

[a]Fifty-year dose commitment from one year of intake.

[b]Read as $2.3 \times 10^{-2}$.

Table 6. Dose commitments[a] from ingestion of beef[b] contaminated from resuspended, contaminated soil. Figures are based on a concentration of 1 pCi/g of each radionuclide in the soil

| Radionuclide | Dose (millirem per year) | | | |
|---|---|---|---|---|
| | Total body | Bone | Kidneys | Lungs |
| Uranium series | | | | |
| $^{238}U$ | 1.0 E-4[c] | 1.1 E-3 | 5.0 E-5 | 5.3 E-8 |
| $^{234}Th$ | 4.6 E-8 | 9.8 E-9 | 4.4 E-9 | 1.3 E-10 |
| $^{234m}Pa$ | 1.6 E-11 | 1.2 E-13 | 6.0 E-13 | 2.9 E-13 |
| $^{234}U$ | 1.1 E-4 | 1.3 E-3 | 5.5 E-5 | 5.4 E-8 |
| $^{230}Th$ | 1.4 E-3 | 1.7 E-2 | 9.6 E-4 | 3.6 E-9 |
| $^{226}Ra$ | 6.4 E-1 | 1.7 | 5.2 E-2 | 1.1 E-4 |
| $^{222}Rn$ | 0.0 | 0.0 | 0.0 | 0.0 |
| $^{218}Po$ | 8.6 E-15 | 5.3 E-14 | 6.5 E-14 | 8.2 E-16 |
| $^{214}Pb$ | 1.0 E-14 | 4.3 E-14 | 8.5 E-14 | 1.4 E-15 |
| $^{214}Bi$ | 1.2 E-13 | 4.5 E-13 | 9.6 E-13 | 2.9 E-14 |
| $^{214}Po$ | 6.1 E-21 | 5.6 E-20 | 1.7 E-21 | 4.8 E-25 |
| $^{210}Pb$ | 5.4 E-3 | 7.4 E-2 | 6.9 E-4 | 1.1 E-7 |
| $^{210}Bi$ | 1.2 E-7 | 2.2 E-7 | 1.3 E-5 | 3.7 E-15 |
| $^{210}Po$ | 5.2 E-2 | 2.3 E-1 | 8.6 E-1 | 2.0 E-9 |
| Actinium series | | | | |
| $^{235}U$ | 1.0 E-4 | 1.2 E-3 | 5.0 E-5 | 1.0 E-7 |
| $^{231}Th$ | 5.7 E-9 | 8.1 E-10 | 4.6 E-10 | 4.5 E-11 |
| $^{231}Pa$ | 1.6 | 2.0 E1 | 8.2 E-1 | 1.8 E-4 |
| $^{227}Ac$ | 8.7 E-1 | 1.1 E1 | 4.0 E-1 | 1.3 E-4 |
| $^{227}Th$ | 5.4 E-7 | 6.3 E-6 | 2.7 E-7 | 4.7 E-10 |
| $^{223}Ra$ | 1.1 E-3 | 2.4 E-3 | 5.7 E-4 | 2.1 E-7 |

Table 6. (continued)

| Radionuclide | Dose (millirem per year) | | | |
|---|---|---|---|---|
| | Total body | Bone | Kidneys | Lungs |
| Actinium series | | | | |
| $^{219}Rn$ | 0.0 | 0.0 | 0.0 | 0.0 |
| $^{211}Pb$ | 1.2 E-14 | 5.9 E-14 | 2.3 E-14 | 2.3 E-16 |
| $^{211}Bi$ | 3.7 E-17 | 5.2 E-18 | 3.9 E-17 | 1.7 E-18 |
| $^{207}Tl$ | 5.1 E-16 | 8.4 E-17 | 4.3 E-17 | 2.4 E-18 |
| Thorium series | | | | |
| $^{232}Th$ | 3.0 E-3 | 3.8 E-2 | 1.8 E-3 | 2.2 E-6 |
| $^{228}Ra$ | 5.2 E-1 | 1.4 | 5.4 E-2 | 3.1 E-4 |
| $^{228}Ac$ | 2.5 E-9 | 1.2 E-8 | 1.8 E-9 | 2.4 E-10 |
| $^{228}Th$ | 2.0 E-4 | 2.3 E-3 | 1.0 E-4 | 4.5 E-8 |
| $^{224}Ra$ | 5.2 E-5 | 1.0 E-4 | 3.3 E-5 | 5.6 E-8 |
| $^{220}Rn$ | 0.0 | 0.0 | 0.0 | 0.0 |
| $^{212}Pb$ | 4.3 E-10 | 4.8 E-9 | 1.8 E-9 | 5.5 E-12 |
| $^{212}Bi$ | 3.9 E-12 | 5.4 E-12 | 1.2 E-10 | 5.6 E-13 |
| $^{208}Tl$ | 1.1 E-15 | 3.5 E-17 | 1.7 E-15 | 8.8 E-16 |
| Plutonium | | | | |
| $^{238}Pu$ | 1.2 E-5 | 1.4 E-4 | 8.3 E-6 | 2.2 E-11 |
| $^{239}Pu$ | 1.4 E-5 | 1.6 E-4 | 9.1 E-6 | 1.7 E-11 |

[a]Fifty-year dose commitment from one year of intake.

[b]Assumed that intake is 0.3 kg/day for beef and that all beef ingested is raised on the contaminated soil.

[c]Read as $1.0 \times 10^{-4}$.

Table 7. Dose commitments[a] from ingestion of milk[b] contaminated via resuspended, contaminated soil.[c] Figures are based on a concentration of 1 pCi/g of each radionuclide in the soil

| Radionuclide | Dose (millirem per year) | | | |
|---|---|---|---|---|
| | Total body | Bone | Kidneys | Lungs |
| Uranium series | | | | |
| $^{238}U$ | 3.5 E-4[d] | 4.0 E-3 | 1.7 E-4 | 1.8 E-7 |
| $^{234}Th$ | 4.7 E-8 | 9.8 E-9 | 4.4 E-9 | 1.3 E-10 |
| $^{234m}Pa$ | 1.6 E-11 | 1.2 E-13 | 6.0 E-13 | 2.9 E-13 |
| $^{234}U$ | 3.9 E-4 | 4.5 E-3 | 1.9 E-4 | 1.9 E-7 |
| $^{230}Th$ | 9.9 E-5 | 1.2 E-3 | 6.9 E-5 | 2.6 E-10 |
| $^{226}Ra$ | 6.2 E-1 | 1.7 | 5.0 E-2 | 1.1 E-4 |
| $^{222}Rn$ | 0.0 | 0.0 | 0.0 | 0.0 |
| $^{218}Po$ | 5.7 E-13 | 3.5 E-12 | 4.3 E-12 | 5.5 E-14 |
| $^{214}Pb$ | 5.5 E-11 | 2.3 E-10 | 4.6 E-10 | 7.7 E-12 |
| $^{214}Bi$ | 1.2 E-11 | 4.3 E-11 | 9.3 E-11 | 2.8 E-12 |
| $^{214}Po$ | 8.8 E-20 | 8.0 E-19 | 2.4 E-20 | 6.9 E-24 |
| $^{210}Pb$ | 2.4 E-2 | 3.3 E-1 | 3.1 E-3 | 4.9 E-7 |
| $^{210}Bi$ | 2.4 E-6 | 4.5 E-6 | 2.7 E-4 | 7.4 E-14 |
| $^{210}Po$ | 7.4 E-3 | 3.3 E-2 | 1.2 E-2 | 2.9 E-10 |
| Actinium series | | | | |
| $^{235}U$ | 3.6 E-4 | 4.1 E-3 | 1.8 E-4 | 3.6 E-7 |
| $^{231}Th$ | 5.7 E-9 | 8.1 E-10 | 4.6 E-10 | 4.5 E-11 |
| $^{231}Pa$ | 4.7 E-4 | 5.9 E-3 | 2.4 E-4 | 5.5 E-8 |
| $^{227}Ac$ | 2.8 E-4 | 3.5 E-3 | 1.3 E-4 | 4.2 E-8 |
| $^{227}Th$ | 7.7 E-7 | 8.6 E-6 | 3.7 E-7 | 6.5 E-10 |
| $^{223}Ra$ | 4.1 E-2 | 8.6 E-2 | 2.1 E-2 | 7.6 E-6 |
| $^{219}Rn$ | 0.0 | 0.0 | 0.0 | 0.0 |

Table 7. (continued)

| Radionuclide | Dose (millirem per year) | | | |
| --- | --- | --- | --- | --- |
| | Total body | Bone | Kidneys | Lungs |
| Actinium series | | | | |
| $^{211}Pb$ | 6.5 E-11 | 3.1 E-10 | 1.2 E-10 | 1.2 E-12 |
| $^{211}Bi$ | 3.7 E-15 | 5.2 E-16 | 3.9 E-15 | 1.7 E-16 |
| $^{207}Tl$ | 7.6 E-13 | 1.2 E-13 | 6.4 E-14 | 3.5 E-15 |
| Thorium series | | | | |
| $^{232}Th$ | 2.0 E-4 | 2.6 E-3 | 1.2 E-4 | 1.5 E-7 |
| $^{228}Ra$ | 1.2 | 3.3 | 1.3 E-1 | 7.4 E-4 |
| $^{228}Ac$ | 2.4 E-10 | 1.1 E-9 | 1.7 E-10 | 2.4 E-11 |
| $^{228}Th$ | 1.9 E-5 | 2.3 E-4 | 9.9 E-6 | 4.5 E-9 |
| $^{224}Ra$ | 5.4 E-3 | 1.1 E-2 | 3.4 E-3 | 5.8 E-6 |
| $^{220}Rn$ | 0.0 | 0.0 | 0.0 | 0.0 |
| $^{212}Pb$ | 1.1 E-6 | 1.2 E-5 | 4.5 E-6 | 1.4 E-8 |
| $^{212}Bi$ | 3.5 E-10 | 4.8 E-10 | 1.1 E-8 | 5.0 E-11 |
| $^{208}Tl$ | 1.6 E-12 | 5.2 E-14 | 2.6 E-12 | 1.3 E-12 |
| Plutonium | | | | |
| $^{238}Pu$ | 3.1 E-6 | 3.5 E-5 | 2.1 E-6 | 5.6 E-12 |
| $^{239}Pu$ | 3.4 E-6 | 4.0 E-5 | 2.3 E-6 | 4.3 E-12 |

[a]Fifty-year dose commitment for one year of intake.

[b]Assumed that intake is 1 liter per day of milk and that all milk consumed is produced on the contaminated soil.

[c]Assumed a resuspension factor of $1 \times 10^{-9}$ $m^{-1}$.

[d]Read as $3.5 \times 10^{-4}$.

Table 8. Dose commitments[a] from ingestion of vegetable crops[b] contaminated by root uptake. Figures are based on a unit concentration of 1 pCi/g of each radionuclide in the soil

| Radionuclide | Dose (millirem per year) | | | |
|---|---|---|---|---|
| | Total body | Bone | Kidneys | Lungs |
| Uranium series | | | | |
| $^{238}U$ | 1.4 E-2[c] | 1.6 E-1 | 6.9 E-3 | 7.3 E-6 |
| $^{234}Th$ | 2.5 E-4 | 5.3 E-5 | 2.4 E-5 | 6.9 E-7 |
| $^{234m}Pa$ | 5.2 E-8 | 4.0 E-10 | 1.9 E-9 | 9.4 E-10 |
| $^{234}U$ | 1.6 E-2 | 1.8 E-1 | 7.8 E-3 | 7.5 E-6 |
| $^{230}Th$ | 5.4 E-1 | 6.5 | 3.7 E-1 | 1.4 E-6 |
| $^{226}Ra$ | 1.0 E-1 | 2.8 E-1 | 8.5 E-3 | 1.8 E-5 |
| $^{218}Po$ | 7.1 E-6 | 4.4 E-5 | 5.4 E-5 | 6.8 E-7 |
| $^{214}Pb$ | 3.4 E-4 | 1.4 E-3 | 2.9 E-3 | 4.7 E-5 |
| $^{214}Bi$ | 3.7 E-5 | 1.3 E-4 | 2.9 E-4 | 8.7 E-6 |
| $^{214}Po$ | 1.1 E-12 | 9.9 E-12 | 3.0 E-13 | 8.6 E-17 |
| $^{210}Pb$ | 2.4 E1 | 3.2 E2 | 3.0 | 4.8 E-4 |
| $^{210}Bi$ | 2.3 E-3 | 4.3 E-3 | 2.6 E-1 | 7.1 E-11 |
| $^{210}Po$ | 2.4 E-1 | 1.1 | 3.9 | 9.2 E-9 |
| Actinium series | | | | |
| $^{235}U$ | 1.4 E-2 | 1.6 E-1 | 7.0 E-3 | 1.5 E-5 |
| $^{231}Th$ | 3.1 E-5 | 4.4 E-6 | 2.5 E-6 | 2.5 E-7 |
| $^{231}Pa$ | 8.4 E-1 | 1.0 E1 | 4.3 E-1 | 9.9 E-5 |
| $^{227}Ac$ | 5.5 E-1 | 6.8 | 2.5 E-1 | 7.9 E-5 |
| $^{227}Th$ | 4.7 E-3 | 5.4 E-2 | 2.3 E-3 | 4.0 E-6 |
| $^{223}Ra$ | 7.9 E-3 | 1.6 E-2 | 4.0 E-3 | 1.5 E-6 |
| $^{219}Rn$ | 0.0 | 0.0 | 0.0 | 0.0 |

Table 8. (continued)

| Radionuclide | Dose (millirem per year) | | | |
|---|---|---|---|---|
| | Total body | Bone | Kidneys | Lungs |
| Actinium series | | | | |
| $^{211}Pb$ | 2.3 E-4 | 1.1 E-3 | 4.1 E-4 | 4.2 E-6 |
| $^{211}Bi$ | 9.1 E-6 | 1.3 E-6 | 9.6 E-6 | 4.2 E-7 |
| $^{207}Tl$ | 1.4 E-5 | 2.3 E-6 | 1.2 E-6 | 6.6 E-8 |
| Thorium series | | | | |
| $^{232}Th$ | 5.4 E-1 | 6.9 | 3.2 E-1 | 3.9 E-4 |
| $^{228}Ra$ | 1.0 E-1 | 2.8 E-1 | 1.1 E-2 | 6.3 E-5 |
| $^{228}Ac$ | 6.0 E-5 | 2.8 E-4 | 4.3 E-5 | 5.9 E-6 |
| $^{228}Th$ | 1.0 E-1 | 1.3 | 5.4 E-2 | 2.4 E-5 |
| $^{220}Rn$ | 0.0 | 0.0 | 0.0 | 0.0 |
| $^{224}Ra$ | 2.3 E-3 | 4.5 E-3 | 1.5 E-3 | 2.5 E-6 |
| $^{212}Pb$ | 2.6 E-2 | 2.9 E-1 | 1.1 E-1 | 3.3 E-4 |
| $^{212}Bi$ | 1.2 E-4 | 1.7 E-4 | 3.7 E-3 | 1.8 E-5 |
| $^{208}Tl$ | 7.2 E-5 | 2.3 E-6 | 1.1 E-4 | 5.9 E-5 |
| Plutonium | | | | |
| $^{238}Pu$ | 9.9 E-4 | 1.1 E-2 | 6.6 E-4 | 1.8 E-9 |
| $^{239}Pu$ | 1.1 E-3 | 1.3 E-2 | 7.3 E-4 | 1.4 E-9 |

[a]Fifty-year dose commitment from one year of intake.

[b]Assumed that ingestion of vegetables is 0.25 kg/day and that all vegetables consumed were grown in the contaminated soil.

[c]Read as $1.4 \times 10^{-2}$.

Table 9. Dose commitments[a] from the ingestion of crops[b] grown in soil irrigated with contaminated water.[c] Figures are based on a unit concentration of 1 pCi/ml of each radionuclide in the water

| Radionuclide | Dose (millirem per year) | | | |
|---|---|---|---|---|
| | Total body | Bone | Kidneys | Lungs |
| Uranium series | | | | |
| $^{238}U$ | 2.4 E-2[d] | 2.7 E-1 | 1.2 E-2 | 1.2 E-5 |
| $^{234}Th$ | 4.3 E-4 | 9.0 E-5 | 4.0 E-5 | 1.2 E-6 |
| $^{234m}Pa$ | 8.8 E-8 | 6.8 E-10 | 3.3 E-9 | 1.6 E-9 |
| $^{234}U$ | 2.7 E-2 | 3.1 E-1 | 1.3 E-2 | 1.3 E-5 |
| $^{230}Th$ | 9.1 E-1 | 1.1 E1 | 6.3 E-1 | 2.4 E-6 |
| $^{226}Ra$ | 1.8 E-1 | 4.7 E1 | 1.4 E-2 | 3.1 E-5 |
| $^{222}Rn$ | 0.0 | 0.0 | 0.0 | 0.0 |
| $^{218}Po$ | 1.2 E-5 | 7.4 E-5 | 9.1 E-5 | 1.2 E-6 |
| $^{214}Pb$ | 5.7 E-4 | 2.4 E-3 | 4.7 E-3 | 8.0 E-5 |
| $^{214}Bi$ | 6.2 E-5 | 2.3 E-4 | 4.9 E-4 | 1.5 E-5 |
| $^{214}Po$ | 1.8 E-12 | 1.7 E-11 | 5.1 E-13 | 1.5 E-16 |
| $^{210}Pb$ | 4.0 E1 | 5.5 E2 | 5.1 | 8.1 E-4 |
| $^{210}Bi$ | 3.9 E-3 | 7.3 E-3 | 4.4 E-1 | 1.2 E-10 |
| $^{210}Po$ | 4.0 E-1 | 1.8 | 6.7 | 1.6 E-8 |
| Actinium series | | | | |
| $^{235}U$ | 2.4 E-2 | 2.8 E-1 | 1.2 E-2 | 2.5 E-5 |
| $^{231}Th$ | 5.2 E-5 | 7.4 E-6 | 4.2 E-6 | 4.2 E-7 |
| $^{231}Pa$ | 1.4 | 1.8 E1 | 7.3 E-1 | 1.7 E-4 |
| $^{227}Ac$ | 9.3 E-1 | 1.2 E1 | 4.2 E-1 | 1.4 E-4 |
| $^{227}Th$ | 8.0 E-3 | 9.1 E-2 | 3.9 E-3 | 6.8 E-6 |
| $^{223}Ra$ | 1.3 E-2 | 2.8 E-2 | 6.7 E-3 | 2.5 E-6 |

Table 9. (continued)

| Radionuclide | Dose (millirem per year) | | | |
|---|---|---|---|---|
| | Total body | Bone | Kidneys | Lungs |
| Actinium series | | | | |
| $^{219}Rn$ | 0.0 | 0.0 | 0.0 | 0.0 |
| $^{211}Pb$ | 3.8 E-4 | 1.8 E-3 | 7.0 E-4 | 7.1 E-6 |
| $^{211}Bi$ | 1.5 E-5 | 2.2 E-6 | 1.6 E-5 | 7.1 E-7 |
| $^{207}Tl$ | 2.4 E-5 | 3.9 E-6 | 2.0 E-6 | 1.1 E-7 |
| Thorium series | | | | |
| $^{232}Th$ | 9.1 E-1 | 1.2 E1 | 5.5 E-1 | 6.7 E-4 |
| $^{228}Ra$ | 1.8 E-1 | 4.7 E-1 | 1.9 E-1 | 1.1 E-4 |
| $^{228}Ac$ | 1.0 E-4 | 4.8 E-4 | 7.3 E-5 | 1.0 E-5 |
| $^{228}Th$ | 1.8 E-1 | 2.1 | 9.1 E-2 | 4.1 E-5 |
| $^{224}Ra$ | 3.9 E-3 | 7.7 E-3 | 2.5 E-3 | 4.2 E-6 |
| $^{220}Rn$ | 0.0 | 0.0 | 0.0 | 0.0 |
| $^{212}Pb$ | 4.3 E-2 | 4.9 E-1 | 1.9 E-1 | 5.6 E-4 |
| $^{212}Bi$ | 2.1 E-4 | 2.9 E-4 | 6.3 E-3 | 3.0 E-5 |
| $^{208}Tl$ | 1.2 E-4 | 3.9 E-6 | 1.9 E-4 | 9.9 E-5 |
| Plutonium | | | | |
| $^{238}Pu$ | 1.7 E-3 | 1.9 E-2 | 1.1 E-3 | 3.0 E-9 |
| $^{239}Pu$ | 1.9 E-3 | 2.2 E-2 | 1.2 E-3 | 2.4 E-9 |

[a]Fifty-year dose commitment from one year of intake.

[b]Assumed that ingestion of vegetables contaminated by root uptake of radionuclides is 0.25 kg per day and that 100% of the food consumed is grown in irrigated soil.

[c]Assumed 15 in. of water used per year on the soil.

[d]Read as $2.4 \times 10^{-2}$.

Table 10. Dose commitments[a] from ingestion[b] of above-surface food contaminated by resuspended[c] soil. Figures are based on a unit concentration of 1 pCi/g of each radionuclide in the soil

| Radionuclide | Dose (millirem per year) | | | |
|---|---|---|---|---|
| | Total body | Bone | Kidneys | Lungs |
| Uranium series | | | | |
| $^{238}U$ | 5.2 E-3[d] | 6.0 E-2 | 2.6 E-3 | 2.7 E-6 |
| $^{234}Th$ | 3.6 E-5 | 7.6 E-6 | 3.4 E-6 | 9.9 E-8 |
| $^{234m}Pa$ | 1.6 E-11 | 1.2 E-13 | 6.0 E-13 | 2.9 E-13 |
| $^{234}U$ | 5.9 E-3 | 6.8 E-2 | 2.9 E-3 | 2.8 E-6 |
| $^{230}Th$ | 8.8 E-3 | 1.1 E-1 | 6.1 E-3 | 2.3 E-8 |
| $^{226}Ra$ | 3.1 E-1 | 8.4 E-1 | 2.6 E-2 | 5.5 E-5 |
| $^{222}Rn$ | 0.0 | 0.0 | 0.0 | 0.0 |
| $^{218}Po$ | 1.2 E-10 | 7.2 E-10 | 8.9 E-10 | 1.1 E-11 |
| $^{214}Pb$ | 6.7 E-9 | 2.8 E-8 | 5.4 E-8 | 9.3 E-10 |
| $^{214}Bi$ | 2.3 E-9 | 8.5 E-9 | 1.8 E-8 | 5.5 E-10 |
| $^{214}Po$ | 1.8 E-17 | 1.6 E-16 | 5.0 E-18 | 1.4 E-2 |
| $^{210}Pb$ | 3.2 E-1 | 4.4 | 4.2 E-2 | 6.6 E-6 |
| $^{210}Bi$ | 3.9 E-5 | 7.4 E-5 | 4.4 E-3 | 1.2 E-12 |
| $^{210}Po$ | 2.2 E-2 | 1.0 E-1 | 3.7 E-1 | 8.7 E-10 |
| Actinium series | | | | |
| $^{235}U$ | 5.4 E-3 | 6.1 E-2 | 2.6 E-3 | 5.5 E-6 |
| $^{231}Th$ | 5.1 E-7 | 7.2 E-8 | 4.1 E-8 | 4.0 E-9 |
| $^{231}Pa$ | 3.1 E-1 | 3.9 | 1.6 E-1 | 3.7 E-5 |
| $^{227}Ac$ | 2.0 E-1 | 2.6 | 9.4 E-2 | 3.0 E-5 |
| $^{227}Th$ | 6.1 E-4 | 6.9 E-3 | 2.9 E-4 | 5.2 E-7 |
| $^{223}Ra$ | 1.1 E-2 | 2.3 E-2 | 5.5 E-3 | 2.0 E-6 |

Table 10. (continued)

| Radionuclide | Dose (millirem per year) | | | |
|---|---|---|---|---|
| | Total body | Bone | Kidneys | Lungs |
| Actinium series | | | | |
| $^{219}Rn$ | 0.0 | 0.0 | 0.0 | 0.0 |
| $^{211}Pb$ | 5.8 E-9 | 2.8 E-8 | 1.1 E-8 | 1.1 E-10 |
| $^{211}Bi$ | 6.4 E-12 | 9.0 E-13 | 6.7 E-12 | 2.9 E-13 |
| $^{207}Tl$ | 1.3 E-11 | 2.2 E-12 | 1.1 E-12 | 6.2 E-14 |
| Thorium series | | | | |
| $^{232}Th$ | 1.2 E-1 | 1.5 | 7.1 E-2 | 8.8 E-5 |
| $^{228}Ra$ | 3.1 E-1 | 8.3 E-1 | 3.3 E-2 | 1.9 E-4 |
| $^{228}Ac$ | 4.1 E-7 | 2.0 E-6 | 3.0 E-7 | 4.2 E-8 |
| $^{228}Th$ | 2.3 E-2 | 2.8 E-1 | 1.2 E-2 | 5.3 E-6 |
| $^{224}Ra$ | 1.5 E-3 | 2.9 E-3 | 9.5 E-4 | 1.6 E-6 |
| $^{220}Rn$ | 0.0 | 0.0 | 0.0 | 0.0 |
| $^{212}Pb$ | 1.1 E-5 | 1.3 E-4 | 4.9 E-5 | 1.5 E-7 |
| $^{212}Bi$ | 2.4 E-8 | 3.4 E-8 | 7.3 E-7 | 3.5 E-9 |
| $^{208}Tl$ | 4.3 E-11 | 1.4 E-12 | 6.9 E-11 | 3.5 E-11 |
| Plutonium | | | | |
| $^{238}Pu$ | 3.7 E-3 | 4.3 E-2 | 2.5 E-3 | 6.7 E-9 |
| $^{239}Pu$ | 4.1 E-3 | 4.8 E-2 | 2.7 E-3 | 5.2 E-9 |

[a] Fifty-year dose commitment for one year of intake.

[b] Assumed that ingestion of vegetables is 0.25 kg per day and that all food consumed is grown in the contaminated soil.

[c] Assumed a resuspension factor of $10^{-9} m^{-1}$.

[d] Read as $5.2 \times 10^{-3}$.

Table 11. Dose commitments[a] from ingestion of drinking water[b] from a contaminated stream. Figures are based on a unit concentration of 1 pCi/ml of each radionuclide in the stream

| Radionuclide | Dose (millirem per year) | | | |
|---|---|---|---|---|
| | Total body | Bone | Kidneys | Lungs |
| Uranium series | | | | |
| $^{238}U$ | 2.7 E1[c] | 3.1 E2 | 1.3 E1 | 1.4 E-2 |
| $^{234}Th$ | 2.9 E-1 | 6.0 E-2 | 2.7 E-2 | 7.9 E-4 |
| $^{234m}Pa$ | 9.9 E-5 | 7.7 E-7 | 3.7 E-6 | 1.8 E-6 |
| $^{234}U$ | 3.0 E1 | 3.5 E2 | 1.5 E1 | 1.4 E-2 |
| $^{230}Th$ | 6.1 E2 | 7.4 E3 | 4.2 E2 | 1.6 E-3 |
| $^{226}Ra$ | 1.6 E3 | 4.3 E3 | 1.3 E2 | 2.8 E-1 |
| $^{222}Rn$ | 0.0 | 0.0 | 0.0 | 0.0 |
| $^{218}Po$ | 3.8 E-3 | 2.3 E-2 | 2.9 E-2 | 3.6 E-4 |
| $^{214}Pb$ | 2.4 E-2 | 1.0 E-1 | 2.0 E-1 | 3.3 E-3 |
| $^{214}Bi$ | 1.2 E-2 | 4.3 E-2 | 9.2 E-2 | 2.8 E-3 |
| $^{214}Po$ | 5.8 E-10 | 5.3 E-9 | 1.6 E-10 | 4.6 E-14 |
| $^{210}Pb$ | 1.7 E3 | 2.3 E4 | 2.1 E2 | 3.4 E-2 |
| $^{210}Bi$ | 7.4 E-1 | 1.4 | 8.3 E1 | 2.3 E-8 |
| $^{210}Po$ | 1.3 E2 | 5.7 E2 | 2.1 E3 | 5.0 E-6 |
| Actinium series | | | | |
| $^{235}U$ | 2.8 E1 | 3.2 E2 | 1.4 E1 | 2.8 E-2 |
| $^{231}Th$ | 3.5 E-2 | 5.0 E-3 | 2.8 E-3 | 2.8 E-4 |
| $^{231}Pa$ | 1.6 E3 | 2.0 E4 | 8.3 E2 | 1.9 E-1 |
| $^{227}Ac$ | 1.1 E3 | 1.3 E4 | 4.8 E2 | 1.5 E-1 |
| $^{227}Th$ | 5.4 | 6.1 E1 | 2.6 | 4.6 E-3 |
| $^{223}Ra$ | 1.2 E2 | 2.5 E2 | 6.1 E1 | 2.3 E-2 |

Table 11. (continued)

| Radionuclide | Dose (millirem per year) | | | |
|---|---|---|---|---|
| | Total body | Bone | Kidneys | Lungs |
| Actinium series | | | | |
| $^{219}Rn$ | 0.0 | 0.0 | 0.0 | 0.0 |
| $^{211}Pb$ | 1.6 E-2 | 7.6 E-2 | 2.9 E-2 | 3.0 E-4 |
| $^{211}Bi$ | 2.9 E-4 | 4.1 E-5 | 3.1 E-4 | 1.3 E-5 |
| $^{207}Tl$ | 2.7 E-4 | 4.5 E-5 | 2.3 E-5 | 1.3 E-6 |
| Thorium series | | | | |
| $^{232}Th$ | 6.1 E2 | 7.9 E3 | 3.7 E2 | 4.5 E-1 |
| $^{228}Ra$ | 1.6 E3 | 4.3 E3 | 1.7 E2 | 9.8 E-1 |
| $^{228}Ac$ | 1.1 E-1 | 5.4 E-1 | 8.3 E-2 | 1.1 E-2 |
| $^{228}Th$ | 1.2 E2 | 1.4 E3 | 6.1 E1 | 2.8 E-2 |
| $^{224}Ra$ | 3.6 E1 | 7.0 E1 | 2.3 E1 | 3.8 E-2 |
| $^{220}Rn$ | 0.0 | 0.0 | 0.0 | 0.0 |
| $^{212}Pb$ | 1.8 | 2.0 E1 | 7.8 | 2.3 E-2 |
| $^{212}Bi$ | 3.9 E-2 | 5.5 E-2 | 1.2 | 5.7 E-3 |
| $^{208}Tl$ | 1.4 E-3 | 4.5 E-5 | 2.2 E-3 | 1.1 E-3 |
| Plutonium | | | | |
| $^{238}Pu$ | 1.9 E1 | 2.2 E2 | 1.3 E1 | 3.5 E-5 |
| $^{239}Pu$ | 2.1 E1 | 2.5 E2 | 1.4 E1 | 2.7 E-5 |

[a] Fifty-year dose commitment for one year of intake.

[b] Assumed that intake is 1.2 liters per day and that all drinking water is taken directly from the stream.

[c] Read as $2.7 \times 10^{1}$.

Table 12. Dose commitments[a] from eating fish[b] from a contaminated stream. Figures are based on a unit concentration of 1 pCi/ml of each radionuclide in the stream

| Radionuclide | Dose (millirem per year) | | | |
|---|---|---|---|---|
| | Total body | Bone | Kidneys | Lungs |
| Uranium series | | | | |
| $^{238}U$ | 4.5 | 5.1 E1[c] | 2.2 | 2.4 E-3 |
| $^{234}Th$ | 1.4 E-1 | 3.0 E-2 | 1.4 E-2 | 3.9 E-4 |
| $^{234m}Pa$ | 1.9 E-5 | 1.4 E-7 | 7.0 E-7 | 3.4 E-7 |
| $^{234}U$ | 5.1 | 5.8 E1 | 2.5 | 2.4 E-3 |
| $^{230}Th$ | 3.1 E2 | 3.7 E3 | 2.1 E2 | 8.0 E-4 |
| $^{226}Ra$ | 1.4 E3 | 3.6 E3 | 1.1 E2 | 2.3 E-1 |
| $^{218}Po$ | 3.2 E-3 | 1.9 E-2 | 2.4 E-2 | 3.0 E-4 |
| $^{214}Pb$ | 1.2 E-1 | 5.1 E-1 | 9.9 E-1 | 1.7 E-2 |
| $^{214}Bi$ | 2.9 E-3 | 1.1 E-2 | 2.3 E-2 | 7.0 E-4 |
| $^{214}Po$ | 4.9 E-10 | 4.4 E-9 | 1.3 E-10 | 3.8 E-14 |
| $^{210}Pb$ | 8.3 E3 | 1.1 E5 | 1.1 E3 | 1.7 E-1 |
| $^{210}Bi$ | 1.8 E-1 | 3.5 E-1 | 2.1 E1 | 5.7 E-9 |
| $^{210}Po$ | 1.1 E2 | 4.7 E2 | 1.8 E3 | 4.1 E-6 |
| Actinium series | | | | |
| $^{235}U$ | 4.6 | 5.3 E1 | 2.3 | 4.7 E-3 |
| $^{231}Th$ | 1.8 E-2 | 2.5 E-3 | 1.4 E-3 | 1.4 E-4 |
| $^{231}Pa$ | 3.1 E2 | 3.8 E3 | 1.6 E2 | 3.6 E-2 |
| $^{227}Ac$ | 4.4 E2 | 5.5 E3 | 2.0 E2 | 6.5 E-2 |
| $^{227}Th$ | 2.7 | 3.1 E1 | 1.3 | 2.3 E-3 |
| $^{223}Ra$ | 1.0 E2 | 2.1 E2 | 5.1 E1 | 1.9 E-2 |
| $^{211}Pb$ | 8.0 E-2 | 3.8 E-1 | 1.5 E-1 | 1.5 E-3 |

Table 12. (continued)

| Radionuclide | Dose (millirem per year) | | | |
|---|---|---|---|---|
| | Total body | Bone | Kidneys | Lungs |
| Actinium series | | | | |
| $^{211}Bi$ | 7.3 E-5 | 1.0 E-5 | 7.7 E-5 | 3.4 E-6 |
| $^{207}Tl$ | 4.5 E-2 | 7.4 E-3 | 3.8 E-3 | 2.1 E-4 |
| Thorium series | | | | |
| $^{232}Th$ | 3.1 E2 | 3.9 E3 | 1.8 E2 | 2.3 E-1 |
| $^{228}Ra$ | 1.4 E3 | 3.6 E3 | 1.4 E2 | 8.1 E-1 |
| $^{228}Ac$ | 4.8 E-2 | 2.3 E-1 | 3.5 E-2 | 4.7 E-3 |
| $^{228}Th$ | 5.9 E1 | 7.2 E2 | 3.1 E1 | 1.4 E-2 |
| $^{224}Ra$ | 3.0 E1 | 5.8 E1 | 1.9 E1 | 3.2 E-2 |
| $^{212}Pb$ | 9.1 | 1.0 E2 | 3.9 E1 | 1.2 E-1 |
| $^{212}Bi$ | 9.9 E-3 | 1.4 E-2 | 3.0 E-1 | 1.4 E-3 |
| $^{208}Tl$ | 2.3 E-1 | 7.4 E-3 | 3.7 E-1 | 1.9 E-1 |
| Plutonium | | | | |
| $^{238}Pu$ | 1.1 | 1.3 E1 | 7.6 E-1 | 2.1 E-6 |
| $^{239}Pu$ | 1.2 | 1.5 E1 | 8.4 E-1 | 1.6 E-6 |

[a] Fifty-year dose commitment for one year of intake.

[b] Assumed that 20 g of fish are consumed daily.

[c] Read as $5.1 \times 10^1$.

Table 13. Dose commitments[a] from inhalation[b] of $^{222}Rn$ in an open area. Figures are based on a unit concentration of 1 pCi/$m^3$ of $^{222}Rn$ and each of its short-lived daughters

| Radionuclide | Dose (millirem per year) | | | | |
|---|---|---|---|---|---|
| | Total body | Bone | Kidneys | Lungs | Bronchial epithelium |
| $^{222}Rn$ | | | | | 1.0[c] |
| $^{218}Po$ | 1.7 E-3[d] | 2.3 E-3 | 3.5 E-3 | 1.0 E-1 | |
| $^{214}Pb$ | 8.2 E-3 | 8.6 E-3 | 2.3 E-2 | 5.0 E-1 | |

[a]Fifty-year dose commitment for one year of intake. Based on 0.3 μm particle size and solubility class W for radon daughters.

[b]Assumed inhalation rate of 23 $m^3$/day and continuous outside exposure.

[c]Includes dose from $^{218}Po$ and $^{214}Pb$.

[d]Read as $1.7 \times 10^{-3}$.

Table 14. Dose commitments[a] from inhalation[b] of $^{222}Rn$ inside a structure having one air change an hour. Figures are based on the outside air concentration of $^{222}Rn$ being 1 $pCi/m^3$

| Radionuclide | Dose (millirem per year) | | | | |
|---|---|---|---|---|---|
| | Total body | Bone | Kidneys | Lungs | Bronchial epithelium |
| $^{222}Rn$ | | | | | 9.9 E-1[c] |
| $^{218}Po$ | 1.6 E-3[d] | 2.1 E-3 | 3.3 E-3 | 9.7 E-2 | |
| $^{214}Pb$ | 4.6 E-3 | 4.8 E-3 | 1.3 E-2 | 2.8 E-1 | |

[a]Fifty-year dose commitments for one year of intake. Based on 0.3 μm particle size and solubility class W for radon daughters.

[b]Assumed inhalation rate of 23 $m^3$/day and continuous exposure inside the structure.

[c]Includes dose from $^{218}Po$ and $^{214}Pb$.

[d]Read as $1.6 \times 10^{-3}$.

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# IV. APPENDIX

The methodology for making estimates of radiation dose to man following release of liquid, gaseous, and particulate radioactive matter has been presented in outline form and selected detail in ORNL reports.[4,5]

## Dose conversion factors

Unit concentrations of radionuclides in the air and water and on soil surfaces were used to estimate the radiation dose to individuals. The factors for converting external exposure to contaminated ground surfaces to dose were calculated with a computer code, EXREM-III.[6] The dose conversion factors and assumptions are given in ORNL-4992. (Ref. 5)

The dose conversion factors for estimating dose from the intake of radionuclides through inhalation and ingestion are available in a report by Dunning *et al.*[4] An adaptation of the Task Group Lung Model[2] is utilized to estimate the retention of radionuclides in the respiratory tract. A model based on the transit times recommended by Eve[3] is used to estimate the retention time of the radionuclides in the GI tract. Retention of other organs is represented by multicompartment models[7] consisting of a series of decaying exponential terms. The details and assumptions of all these models are discussed in the report by Dunning *et al.*[4]

Sample problems for internal dose calculations are shown on pp. 4-108 and 4-109 of ORNL-4992. (Ref. 5)

## Environmental parameters

Many of the basic environmental parameters used in the dose calculations are conservative; that is, the values were chosen to maximize intake or exposure to man. In estimating the external exposure to man in Table

3, many factors that would reduce the radiation dose, such as time spent away from the reference location and shielding provided by structures, were not considered. Site-specific information or more realistic estimates may be used to reduce the doses accordingly. In estimating doses via ingestion of vegetables, beef, milk, and water, an individual was assumed to have obtained all of his foods and drinking water at the location of the contamination. In estimating the dose from the ingestion of fish, the daily intake by the individual was assumed to be 20 g. The bioaccumulation factors for freshwater fish are listed in ORNL-4992 (Ref. 5) and have been derived for the most part from UCRL-50564. (Ref. 9)

Shielding factors

The effect of building shielding was used to estimate the doses in Table 4 from gamma radiation originating from outside, contaminated ground surfaces. The dose reduction factors used were based on a model developed by Kocher.[10]

For estimating the doses in Tables 3 and 4 for exposure to contaminated ground surfaces, it was assumed that there was no shielding due to terrain or geological features.

Radon-222 and daughter concentrations inside structures

The maximum exposure to $^{222}$Rn progeny will occur in poorly ventilated structures. In Table 14, where the doses from exposure to $^{222}$Rn and daughter concentrations inside the home were calculated, one air change per hour was used. Concentrations of the daughters $^{218}$Po and $^{214}$Pb based on an outside unit concentration of $^{222}$Rn were calculated using the RADONDAVENT computer code.[11]

Resuspended air activity

After airborne particulates have been removed from the atmosphere and reach the ground by deposition, they may again enter the atmosphere via resuspension processes. Becoming airborne, they may be inhaled or they may settle out onto food crops and grasses and be ingested in vegetables, beef, and milk. In this study for normal resuspension, that is, by wind for old depositions, a resuspension factor of $1 \times 10^{-9}\ m^{-1}$ (Ref. 12) was used. A factor of $1 \times 10^{-7}\ m^{-1}$ was used to estimate exposures during periods of mechanical disturbances.[3]

The following expression was used to estimate intake via inhalation of resuspended radionuclides:

$$\text{Ci year}^{-1} = (\text{Ci m}^{-2})\ (1 \times 10^{-9}\ \text{m}^{-1})\ (7300\ \text{m}^3\ \text{year}^{-1}),$$

where

$\text{Ci year}^{-1}$ is the intake,

$1 \times 10^{-9}\ m^{-1}$ is the resuspension factor, and

$7300\ m^3$ is the air inhaled $\text{year}^{-1}$.

Root uptake of contamination

For the ingestion of food contaminated by the root uptake of radionuclides deposited on the soil, it was assumed that (1) plant material accumulates a concentration, $C_f$, of radionuclides in the soil in which the plants grow and (2) downward movement of the radionuclides in the soil does not continue beyond the root zone (15 cm). With a soil density of $1.5\ g\ cm^{-3}$, the radionuclides deposited on a square meter are contained in $2.25 \times 10^5$ g of soil. The following expression is used to estimate the intake via ingestion of plants:

$$\text{Ci year}^{-1} = (\text{Ci m}^{-2}/2.25 \times 10^5 \text{ g m}^{-2})\ (C_f)\ (9.12 \times 10^4 \text{ g year}^{-1}),$$

where

Ci $\text{year}^{-1}$ is the amount ingested,

$9.12 \times 10^4$ g is the plant ingested $\text{year}^{-1}$.

Additional intake from ingestion of plants contaminated by the deposition of resuspended radionuclides was calculated using the TERMOD code.[8] The daily intake (μCi per day) of radionuclides from continuous deposition of 1 μCi/$m^2$ per day is listed in ORNL 4992 (Ref. 5) for above-surface food, beef, and milk.

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